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Does It Matter Whether Capital is Fixed or
Circulating? -- A Wicksellian Exercise

Hans J. Brems

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--A Wicksellian Exercise

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DOES IT MATTER WHETHER CAPITAL IS FIXED OR CIRCULATING?

—A WICKSELLIAN EXERCISE

100-WORD ABSTRACT

Before the fiftieth anniversary of the Swedish School this Wicksellian exercise sees fixed capital as a stock of machines with variable useful life and circulating capital as a wage fund with variable period of production. The paper applies to both forms the mathematical technique that Wicksell, towards the end of his life, applied to only one of them. For either form three remarkably simple interest elasticities result: the elasticity of length of time, the elasticity of demand for capital, and the elasticity of aggregate physical output. Between the two forms such elasticities differ either not at all or very little.

DOES IT MATTER WHETHER CAPITAL IS FIXED OR CIRCULATING?
--A WICKSELLIAN EXERCISE

By HANS BREMS

I. FIXED AND CIRCULATING CAPITAL

Capital is necessary in production, and its necessity has something to do with time. In the capitalist production process, what precisely is it that takes time? Two different types of capital have been distinguished by economists, i.e., fixed and circulating capital, and we cannot improve on Ricardo's [1821 (1951: 31)] description: "A brewer, whose buildings and machinery are valuable and durable, is said to employ a large portion of fixed capital: on the contrary, a shoemaker, whose capital is chiefly employed in the payment of wages ... is said to employ a large proportion of his capital as circulating capital."

In the case of fixed capital, then, what takes time is the utilization of durable plant and equipment. In the case of circulating capital what takes time is the maturing of output in slow organic growth in agriculture, cattle-raising, forestry, and winery or in time-consuming construction. On fixed capital Böhm-Bawerk [1888 (1923)] was silent, and so was Wicksell [1893 (1954, 1970)] and [1901

(1934, 1967)] until his [1923 (1934)] mathematical restatement of Åkerman (1923).

The purpose of the present paper is to see if it matters whether capital is fixed or circulating. The best way to see if it does is to treat both forms by the same mathematical technique, i.e., the technique chosen by Wicksell in his mathematical restatement of Åkerman.

II. FIXED CAPITAL (ÅKERMANN):

CAPITAL AS A STOCK OF MACHINES WITH VARIABLE USEFUL LIFE

1. Variables

a_1 \equiv labor employed in building one physical unit of producers' good of vintage v

D \equiv demand for capital

D_v \equiv present depreciated worth of capital stock of vintage v

d_v \equiv accumulated depreciation allowances of capital stock of vintage v

δ_v \equiv present nondepreciated worth of capital stock of vintage v

J \equiv present net worth of an endless succession of replacements

j \equiv present net worth of capital stock of vintage v

$k \equiv$ present gross worth of capital stock of vintage v

$L \equiv$ labor employed in building and operating producers' goods of vintage v

$L_1 \equiv$ labor employed in building producers' goods of vintage v

$L_2 \equiv$ labor employed in operating producers' goods of vintage v

$P \equiv$ price of consumers' goods

$p \equiv$ price of producers' goods

$r \equiv$ rate of interest

$S \equiv$ physical capital stock of producers' goods of vintage v installed per annum

$S_u \equiv$ physical capital stock of producers' goods of all vintages in operation

$X \equiv$ physical output produced by physical capital stock of vintage v

$u \equiv$ useful life of producers' goods

2. Parameters

$a_2 \equiv$ labor employed in operating one physical unit of producers' good of vintage v

$\beta \equiv$ elasticity of building labor a_1 with respect to useful life u

$F \equiv$ available labor force

$m \equiv$ a multiplicative factor in (4)

$w \equiv$ money wage rate, a numéraire

The symbol e is Euler's number, the base of natural logarithms.

3. Building Labor and Operating Labor

Ricardo [1821 (1951)] did consider fixed capital ("machinery"). His tool was a distinction since forgotten, i.e., the distinction between building labor and operating labor.

Let producers' goods be produced from labor alone, and let a_1 be the labor employed in building one physical unit, then labor employed in building producers' goods of vintage v is

$$L_1 = a_1 S \tag{1}$$

Let a_2 be the labor employed in operating one physical unit of producers' goods, then labor employed in operating producers' goods of vintage v is

$$L_2 = a_2 S \tag{2}$$

Let the money wage rate be w . Under pure competition and freedom of entry and exit the price of producers' goods will then equal their cost of production:

$$p = a_1 w \quad (3)$$

Now do something un-Ricardian and let useful life u be a variable and a_1 a rising function of it but rising in less than proportion:

$$a_1 = mu^\beta \quad (4)$$

where $0 < \beta < 1$ as Wicksell [1923 (1934: 276)] assumed.

4. Present Net Worth of an Endless Succession of Replacements

At time v let an entrepreneur consider installing a physical capital stock S of vintage v whose useful life is u . Samuelson (1966: 568) defined reswitching as the "switching back at a very low interest rate to a set of techniques that seemed viable only at a very high interest rate." To rule out such reswitching we assume, as Wicksell [1923 (1934: 274)] did, our entrepreneur to be producing the annual physical output of X of consumers' goods uniformly throughout the useful

life u . Let that annual physical output be the same for more or less durable capital stock of vintage v , and let that output sell at price P . Then annual revenue of such capital stock will be PX and annual revenue minus operating labor cost will be

$$H \equiv PX - a_2 Sw \quad (5)$$

Per small fraction dt of a year located at time t where $v \leq t \leq v + u$ such revenue minus operating labor cost is Hdt . As seen from time v its present worth is $e^{-r(t-v)}Hdt$, and the present worth of all such future revenue minus operating cost will be the integral

$$k \equiv \int_v^{v+u} e^{-r(t-v)} H dt = \frac{1 - e^{-ru}}{r} H \quad (6)$$

As seen from time v define the present net worth j of the capital stock S as its gross worth k minus its cost of acquisition pS or, using (6):

$$j = \frac{1 - e^{-ru}}{r} H - pS \quad (7)$$

Every u th year the entrepreneur installs another vintage of physical capital stock S priced p and replacing a retired one. As seen from time $v + iu$, the time of installing the i th vintage of physical capital stock, the net worth of that vintage is still j . But as seen from time v , the time of installing the first vintage, the net worth of the i th vintage is $e^{-iru}j$. Let i rise without bounds, use (3) and (4), and find the net worth as seen from time v of an endless succession of replacements to be

$$J \equiv j(1 + e^{-ru} + e^{-2ru} + \dots) = \frac{j}{1 - e^{-ru}} = \frac{H}{r} - \frac{mSu^{\beta}w}{1 - e^{-ru}} \quad (8)$$

in which useful life u appears only in the last term.

5. Elasticity of Optimal Useful Life with Respect to Rate of Interest

Taking his β , H , m , r , S and w as given, the entrepreneur will maximize his present worth J with respect to his useful life u . Take the partial derivative of (8) with respect to u , set it equal to zero, and find a transcendental first-order maximum condition:

$$(1 - e^{-ru})\beta - rue^{-ru} = (e^{ru} - 1)\beta - ru = 0 \quad (9)$$

or, rearranged, Wicksell's [1923 (1934: 278-279)] own form

$$e^{ru} = 1 + \frac{ru}{\beta} \quad (10)$$

for his n , v , and ρ are our u , β , and r , respectively.

How does optimal useful life u depend on the rate of interest r ? Differentiate Wicksell's form (10) implicitly with respect to r , recalling that r and u are now varying together:

$$\left(r \frac{du}{dr} + u\right) \left(e^{ru} - \frac{1}{\delta}\right) = 0 \quad (11)$$

from which we find the elasticity of optimal useful life with respect to the rate of interest

$$-\frac{r}{u} \frac{du}{dr} = -1 \quad (12)$$

or, in Wicksell's [1923 (1934: 278)] words: "it follows that the product of the rate of interest (with continuously compound interest) and the optimal lifetime of the axe is a constant..."

6. Demand for Capital in a Single Vintage at Time τ

At time v another vintage of physical capital stock S priced p is installed. As seen from time τ , where $v \leq \tau \leq v + u$, its present non-depreciated worth is

$$\delta_v(\tau) \equiv e^{r(\tau - v)} p_S \quad (13)$$

Entrepreneurs split their current revenue PX in two parts. The first part a_2Sw is immediately paid out as the wage bill of operating labor L_2 . Under pure competition and freedom of entry and exit entrepreneurs can earn no profit over and above depreciation and interest, so the second part of current revenue $H \equiv PX - a_2Sw$, defined by (5), is set aside on compound interest as depreciation allowance. The depreciation allowance per small fraction dt of a year located at time t is Hdt . As seen from time τ the present worth of it is $e^{r(\tau - t)}Hdt$, and the present worth of depreciation allowances accumulated between time v and time τ on all producers' goods of vintage v is the integral

$$d_v(\tau) \equiv \int_v^{\tau} e^{r(\tau - t)} H dt = \frac{e^{r(\tau - v)} - 1}{r} H \quad (14)$$

Still at time τ , then, present depreciated worth of the vintage v is its present nondepreciated worth minus its accumulated depreciation allowances:

$$D_v(\tau) \equiv \delta_v(\tau) - d_v(\tau) = e^{r(\tau - v)} pS - \frac{e^{r(\tau - v)} - 1}{r} H \quad (15)$$

7. Producers' Goods Fully Written Off at End of Life

At the end of the useful life of the vintage, i.e., at time $v + u$ present depreciated worth of the vintage will become zero. So in (15) replace τ by $v + u$, set the outcome equal to zero, and use it to express H/r in terms of pS :

$$\frac{H}{r} = \frac{e^{ru}}{e^{ru} - 1} pS = \frac{1}{1 - e^{-ru}} pS \quad (16)$$

Insert (16) into (15) and write present depreciated worth of the vintage v as

$$D_v(\tau) = \frac{1 - e^{r(\tau - u - v)}}{1 - e^{-ru}} pS \quad (17)$$

8. Elasticity of Demand for Capital in All Vintages with Respect to Rate of Interest

Each year another vintage of physical capital stock S producing uniformly an annual physical output X is installed. Then in our stationary economy at any time u vintages will remain in operation.

We now wish to find the depreciated present worth as seen from time τ of all the u vintages in operation at time τ . To do so we must integrate (17) from $v = \tau - u$ to $v = \tau$ with respect to vintage v . Here, $S \equiv$ physical capital stock of producers' goods of vintage v contains no v , and neither does its price p . So we find the integral to be

$$D(\tau) \equiv \int_{\tau - u}^{\tau} D_v(\tau) dv = \left(\frac{u}{1 - e^{-ru}} - \frac{1}{r} \right) pS$$

Factor out useful life u and write present depreciated worth of aggregate capital stock

$$D(\tau) = \left(\frac{1}{1 - e^{-ru}} - \frac{1}{ru} \right) pSu \quad (18)$$

While $S \equiv$ physical capital stock of producers' goods of vintage v , $S_u \equiv$ physical capital stock of producers' goods of all vintages in operation. At full employment how large a stock S_u can be sustained?

At time τ , as at any other time, a capital stock of S of that vintage is being built, and according to (1) the labor employed in building it is $L_1 = a_1 S$. At time τ , as at any other time, a capital stock S_u is in operation, and according to (2) the labor employed in operating it is $L_2 u = a_2 S_u$. Assume full employment:

$$L_1 + L_2 u = (a_1/u + a_2) S_u = F \quad (19)$$

Use (4) and find sustainable aggregate physical capital stock

$$S_u = \frac{F}{\mu^{\beta} - 1 + a_2} \quad (20)$$

Into (18) insert (3), (4), and (20) and find present depreciated worth of sustainable aggregate physical capital stock

$$D(\tau) = \left(\frac{1}{1 - e^{-ru}} - \frac{1}{ru} \right) \frac{\mu u^\beta}{\mu u^\beta - 1 + a_2} Fw \quad (21)$$

Now according to (12) the elasticity of optimal useful life u with respect to the rate of interest r was minus one, consequently r and u are in inverse proportion, and their product ru is some constant. F and w are parameters. That leaves useful life u as the only variable occurring on the right-hand side of (21). But according to (12) useful life u is a function of the rate of interest r , and the elasticity of $D(\tau)$ with respect to the rate of interest r is

$$\frac{r}{D(\tau)} \frac{dD(\tau)}{dr} = \frac{r}{D(\tau)} \frac{dD(\tau)}{du} \frac{du}{dr} = - \frac{a_1 + \beta a_2 u}{a_1 + a_2 u} \quad (22)$$

which is a negative proper fraction, because $0 < \beta < 1$.

The rate of interest equilibrates the demand for capital $D(\tau)$ with available supply of it. If the rate of interest were higher than its equilibrium value a shorter useful life would be optimal. Excess supply in the capital market would result, and competition among lenders would put a downward pressure on the rate of interest. Vice versa if the rate of interest were lower than its equilibrium value.

9. Elasticity of Aggregate Physical Output with Respect to Rate of Interest

At full employment F but shorter useful life u , aggregate physical output uX per annum from producers' goods of all vintages in operation would be down: If annual physical output is the same for more or less durable capital stock of vintage v , then X is in direct proportion to S and uX in direct proportion to $Su \equiv$ sustainable aggregate physical capital stock (20). The elasticity of (20) with respect to useful life u is

$$\frac{u}{Su} \frac{d(Su)}{du} = (1 - \beta) \frac{\mu u^{\beta} - 1}{\mu u^{\beta} - 1 + a_2}$$

and with respect to the rate of interest r is, using (12):

$$\frac{r}{Su} \frac{d(Su)}{dr} = \frac{r}{Su} \frac{d(Su)}{du} \frac{du}{dr} = - (1 - \beta) \frac{\mu^\beta - 1}{\mu^\beta - 1 + a_2} \quad (23)$$

which is a negative proper fraction, because $0 < \beta < 1$.

Example: if long-lived trolley buses were replaced by diesel buses of half the useful life u , then twice as many new buses S would have to be acquired annually to keep up a fleet of Su buses. Building labor a_1 per new bus would be down but in less than proportion to u . If only a given labor force were available to build and operate buses, a smaller fleet Su , delivering fewer seat-miles per annum, would have to do.

Let us now treat circulating capital by the same mathematical technique.

III. CIRCULATING CAPITAL (BÖHM-BAWERK):

CAPITAL AS A WAGE FUND WITH A VARIABLE PERIOD OF PRODUCTION

1. Variables

- $D \equiv$ demand for capital
- $D_v \equiv$ present worth of wage bills paid in production run of vintage v
- $J \equiv$ present net worth of an endless succession of production runs
- $j \equiv$ present net worth of a production run of vintage v
- $L \equiv$ labor employed in a production run of vintage v
- $L_y \equiv$ labor employed in y vintages of production runs
- $P \equiv$ price of consumers' goods
- $r \equiv$ rate of interest
- $W \equiv$ money wage bill per annum in a production run
- $W_y \equiv$ money wage bill per annum in y vintages of production runs
- $X \equiv$ physical output maturing at the end of a production run of vintage v
- $X_y \equiv$ physical output to mature at the end of y vintages of production runs
- $y \equiv$ period of production

2. Parameters

$\alpha \equiv$ elasticity of physical output per annum per man $X/(Ly)$ with respect to period of production

$F \equiv$ available labor force

$m \equiv$ a multiplicative factor in (24)

$w \equiv$ money wage rate, a numéraire

3. Present Net Worth of an Endless Succession of Production Runs

At time v let an entrepreneur consider engaging himself in a production run of vintage v whose period of production is y . Again, to rule out reswitching we assume, as Böhm-Bawerk always did, our entrepreneur to be employing L men uniformly throughout the period of production y of his production run of vintage v . At the end of the period, at time $v + y$, a physical output of X of consumers' goods would be maturing.

But let the period of production y be a variable and physical output per annum per man $X/(Ly)$ a rising function of it but rising in less than proportion:

$$X/(Ly) = my^{\alpha} \tag{24}$$

where $0 < \alpha < 1$. Neither in [1893 (1954)] nor in [1901 (1934)] did Wicksell write, let alone use, such a production function.

At time $t = v + y$ the entrepreneur will sell his physical output X at price P , so his revenue will be PX . As seen from time $t = v$ the present worth of that revenue will be $e^{-ry}PX$.

The L men are employed continuously at the money wage rate w . The annual wage bill of the production run will then be

$$W \equiv Lw \tag{25}$$

Per small fraction dt of a year located at time t where $v \leq t \leq v + y$ such a wage bill is Wdt . As seen from time v its present worth is $e^{-r(t-v)}Wdt$, and the present worth of all such future wage bills will be the integral

$$\int_v^{v+y} e^{-r(t-v)} Wdt = \frac{1 - e^{-ry}}{r} W \tag{26}$$

Define the present net worth j of the entire production run as the present worth of its revenue minus the present worth of all its wage bills or, using (25):

$$j \equiv e^{-ry} PX - \frac{1 - e^{-ry}}{r} Lw \quad (27)$$

Every y th year the entrepreneur starts another vintage of production runs employing L men continuously at the money wage rate w . As seen from time $v + iy$, the time of starting the i th vintage of production run, the net worth of that vintage is still j . But as seen from time v , the time of starting the first vintage, the net worth of the i th vintage is $e^{-iry}j$. Let i rise without bounds, use (24) and (27), and find the net worth as seen from time v of an endless succession of production runs to be

$$J \equiv j(1 + e^{-ry} + e^{-2ry} + \dots) = \frac{j}{1 - e^{-ry}} = \left(\frac{mPy^{\alpha} + 1}{e^{ry} - 1} - \frac{w}{r} \right) L \quad (28)$$

in which the period of production y appears only in the first term.

4. Elasticity of Optimal Period of Production with Respect to Rate of Interest

Taking his α , L , m , P , r , and w as given, the entrepreneur will maximize his present net worth J with respect to his period of production y . Take the partial derivative of (28) with respect to y , set it equal to zero, and find a transcendental first-order maximum condition:

$$e^{ry}(\alpha + 1 - ry) - (\alpha + 1) = 0 \quad (29)$$

How does optimal period of production y depend on rate of interest r ? Differentiate (29) implicitly with respect to r , recalling that r and y are now varying together:

$$\left(r \frac{dy}{dr} + y\right)e^{ry}(\alpha - ry) = 0 \quad (30)$$

from which we find the elasticity of the optimal period of production with respect to the rate of interest

$$\frac{r}{y} \frac{dy}{dr} = -1 \quad (31)$$

5. Demand for Capital in a Single Vintage at Time τ

At time v another vintage of production run is started paying the wage bill Wdt per small fraction dt of a year located at time t where $v \leq t \leq \tau$. As seen from time τ its present worth is $e^{r(\tau - t)} Wdt$, and the present worth of all wage bills paid between time v and time τ in the production run of vintage v is the integral

$$D_v(\tau) \equiv \int_v^{\tau} e^{r(\tau - t)} Wdt = \frac{e^{r(\tau - v)} - 1}{r} W \quad (32)$$

6. Elasticity of Demand for Capital in All Vintages with Respect to Rate of Interest

Each year another vintage of production runs uniformly employing L men at the money wage rate w is started. Then in our stationary economy at any time y vintages will remain in operation.

We now wish to find the present worth as seen from time τ of all wage bills paid between time $\tau - y$ and time τ in production runs of all the y vintages in operation at time τ . To do so we must integrate (32) from $v = \tau - y$ to $v = \tau$ with respect to vintage v . Here, $W \equiv$ money wage bill per annum in a production run of vintage v contains no v , and neither does the rate of interest r . So we find the integral to be

$$D(\tau) \equiv \int_{\tau - y}^{\tau} D_v(\tau) dv = \frac{e^{ry} - 1 - ry}{r} \frac{W}{r}$$

Factor out the period of production y and write

$$D(\tau) = \frac{e^{ry} - 1 - ry}{ry} \frac{Wy}{r} \quad (33)$$

While $W \equiv$ money wage bill per annum in a production run of vintage v , $Wy \equiv$ money wage bill per annum in production runs of all vintages in operation. Assume full employment

$$Ly = F, \quad (34)$$

use (25), and write (33) as

$$D(\tau) = \frac{e^{ry} - 1 - ry}{ry} \frac{Fw}{r} \quad (35)$$

Now according to (31) the elasticity of optimal period of production y with respect to the rate of interest r was minus one, consequently r and y are in inverse proportion, and their product ry is some constant. F and w are parameters. That leaves the rate of interest r as the only variable occurring on the right-hand side of (35), and the elasticity of $D(\tau)$ with respect to the rate of interest r is

$$\frac{r}{D(\tau)} \frac{dD(\tau)}{dr} = -1 \quad (36)$$

The rate of interest equilibrates the demand for capital $D(\tau)$ with available supply of it. If the rate of interest were higher than its

equilibrium value a shorter period of production would be optimal. Excess supply in the capital market would result, and competition among lenders would put a downward pressure on the rate of interest. Vice versa if the rate of interest were lower than its equilibrium value.

7. Elasticity of Aggregate Physical Output with Respect to Rate of Interest

At full employment F but shorter period of production y , aggregate physical output X per annum from production runs of all vintages in operation would be down: according to (24) physical output per annum per man $X/(Ly) = my^\alpha$. According to (34) aggregate employment is full: $Ly = F$, so aggregate physical output $X = Fmy^\alpha$, consequently the elasticity of aggregate physical output with respect to period of production is

$$\frac{y}{X} \frac{dX}{dy} = \alpha$$

and with respect to the rate of interest r is, using (31):

$$\frac{r}{X} \frac{dX}{dr} = -\frac{r}{X} \frac{dX}{dy} \frac{dy}{dr} = -\alpha \quad (37)$$

which is a negative proper fraction, because $0 < \alpha < 1$. Example: if trees were allowed to stand only half as long before cut, twice as large annual hiring of labor L to plant new trees would be required to keep aggregate employment Ly full. But aggregate physical output X of timber per annum would be down when trees were cut sooner.

IV. SUMMARY AND CONCLUSION

Does it matter, then, whether capital is fixed and has a useful life of u or circulating and has a period of production y ? Assuming the relevant production functions to be of constant-elasticity form, having the elasticities β and α , respectively with respect to those lengths of time, we have found the following answers.

First, whether capital is fixed or circulating does not matter at all for the elasticities of optimal useful life or optimal period of

production with respect to the rate of interest: both elasticities are minus one.

Second, it matters little for the elasticities of the demand for capital with respect to the rate of interest: both are negative, one a negative proper fraction, the other minus one.

Third, it matters little for the elasticities of aggregate physical output with respect to the rate of interest: both are negative, one a negative proper fraction, the other minus the elasticity α of physical output per annum per man with respect to the period of production.

We must agree, then, with Wicksell [1919 (1934: 240)] that "from an economic point of view the difference is ... unessential."

Our answers were found under assumptions ruling out reswitching: physical output was assumed to be produced uniformly over useful life and labor to be employed uniformly over the period of production. Samuelson (1966: 571-574) relaxed both assumptions, thus finding reswitching equally possible in both cases. Equally possible, perhaps, but hardly equally likely: Aren't durable producers' goods typically designed to produce uniformly throughout their useful lives, whereas ripening wine or growing timber typically do not employ labor uniformly throughout their period of production?

Wicksell's system was a world of simple beauty. He could have enhanced its simplicity and beauty, had he treated fixed and circulating capital uniformly. To show that such a treatment is feasible was the purpose of the present paper.

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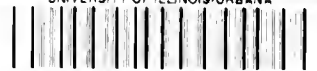
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